The Cangzhou Clean Air Project Blueprint:

How cities can use hyperlocal air pollution monitoring data to locate hotspots accurately and improve enforcement efficiency

EDF ENVIRONMENTAL DEFENSE FUND

Finding the ways that work

CONTENTS

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INTRODUCTION

Rapid economic growth, stimulated by a policy of reform and opening-up, has helped the majority of cities in China – including Cangzhou – increase the wealth of its population and provide employment and development opportunities. However, the rapid growth has come with a price: air pollution is an unintended and significant side effect. Particulate matter, as well as other air pollutants from transport, energy production, and manufacturing, provoke periods of smoke and haze.

In the process of improving air quality, the Ministry of Ecology and Environment (MEE) of China found that organizing air quality monitoring and initiating enforcement activities with local environmental authorities is one of the key factors in improving China's air quality. The on-site inspections conducted by local environmental inspectors are usually organized according to routine inspection plans, or triggered by complaints from the public about pollution incidents.

However, the existing air quality enforcement system is still far from being effective and efficient. It is difficult for environmental inspectors to identify hotspots of pollution accurately, which could help pinpoint the source of violations. For example, since the launch of China's three-year "Blue Sky" campaign in 2018, MEE launched the Strengthening Supervision Program, a major enforcement campaign against air pollution, conducted in 39 cities including the Beijing-Tianjin-Hebei region and other key control areas. Out of the 925,000 on-site inspections in 2019, the program identified 65,000 air pollution-related problems (some are violations; others are behaviors related to pollution, but not regarded as violations), resulting in a detection rate of air pollution problems (including but not limited to $PM_{2.5}$) of 7% among fixed pollution sources.[1]

New lower-cost mobile sensor technology is changing that dynamic, allowing us to map air pollution street-by-street and identify patterns and hotspots like never before. To meet the ongoing challenge of air pollution, the City of Cangzhou – in partnership with Environmental Defense Fund's Beijing Office (EDF China), HD Environmental Consortium, and SUSTC Engineering Technology Innovation Centre (Beijing) – launched the Cangzhou pilot project, which mapped and measured air pollution within the central city area over two years.

The pilot project aims to demonstrate how monitoring technologies can deliver hyperlocal data that helps environmental inspectors locate hotspots accurately and improves enforcement efficiency, providing a data-driven solution to improve air quality.

[1] http://www.mee.gov.cn/xxgk2018/xxgk/xxgk15/202001/t20200118_760088.html

Air quality improvement in China

In 2020 in China, the average level of particulate matter of 2.5 microns or smaller ($PM_{2.5}$) monitored by MEE in 338 cities nationwide stood at 33 micrograms per cubic meter, 34% less than in 2015.

Despite this progress, 60% of cities still do not meet the national annual standard for $PM_{2.5}$ (35 micrograms per cubic meter), which itself is 3.5 times weaker than World Health Organization (WHO) guidelines. (Figure 1)

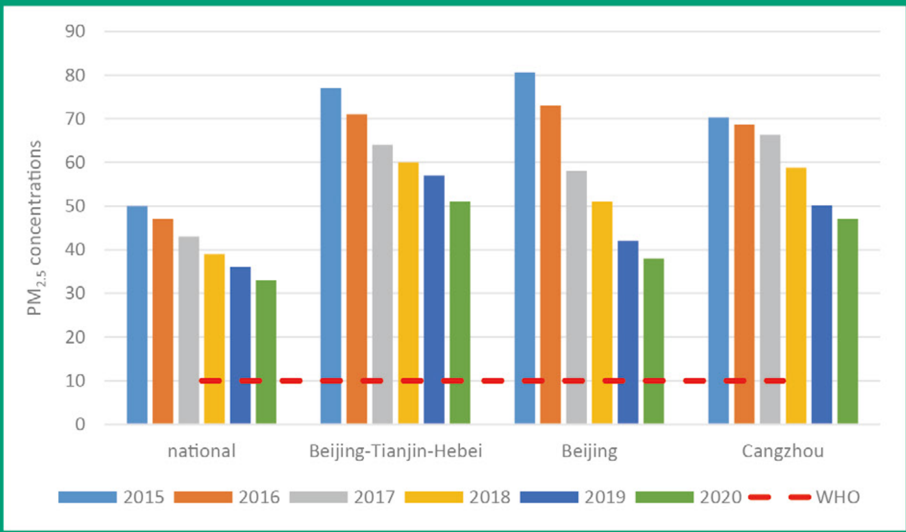


Figure 1. Annual $PM_{2.5}$ concentration Comparison from 2015 to 2020

We hope this guideline illuminates how mobile monitoring can be combined with existing monitoring networks in one city to identify hotspots at a finer scale with full consideration of characteristics of local pollution, as well as improve the efficiency of existing enforcement systems for air quality improvement in other cities.

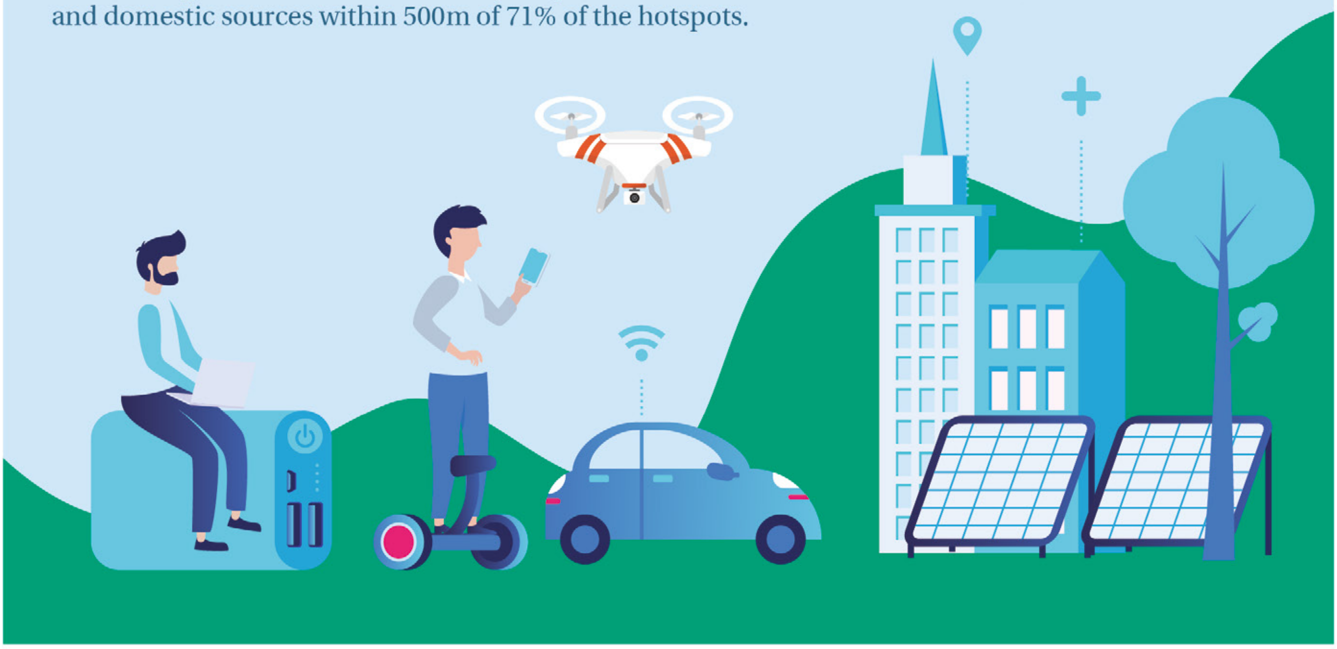
[2] In 2019, since Laiwu City has been merged into Jinan City, the number of cities at or above prefecture level has been changed from 338 to 337.

REPLICATING BEST PRACTICES

What we learned

The hyperlocal mapping dataset that includes fixed monitoring and mobile monitoring, emission inventory, and meteorological data, can characterize air pollution at the street level, help inspectors locate air pollution hotspots (100m by 100m) more accurately, and improve the supervision efficiency. These hotspots are locations with elevated $PM_{2.5}$ concentrations, either higher than surrounding areas or above a certain threshold, that are based on available fixed and mobile monitoring data.

With the data-driven air quality monitoring and enforcement system, the local environmental inspectors in Cangzhou were able to identify suspected emission sources such as traffic, construction sites, and domestic sources within 500m of 71% of the hotspots.



THE SCIENTIFIC GAINS FROM THE CANGZHOU CLEAN AIR PROJECT

The integrated air quality monitoring network in Cangzhou provided a solid foundation for developing a more robust methodology to locate hotspots timely and precisely. The Cangzhou Clean Air pilot project demonstrated that – with reliable hyperlocal monitoring data and other emission sources dataset in place – an accurate and efficient hotspot identification and inspection mechanism can be established. Scientific advancements also include:

Scientific and robust quality assurance and quality control (QA/QC) procedures

In Cangzhou, there are two different air pollutant concentration datasets: mobile monitoring data and stationary sensors data. Both of them are calibrated by their providers before being shared with EDF. Because their calibration method is unknown, we must ensure the accuracy and precision of the data. We developed multiple QA/QC methods to remove corrupt, inaccurate, and incomplete records and to identify equipment malfunctions. We also flagged equipment identified for further analysis and shared the results with their manufacturer periodically to improve the quality control process.

Data integration of fixed and mobile monitoring data as the basis to perform hotspot identification

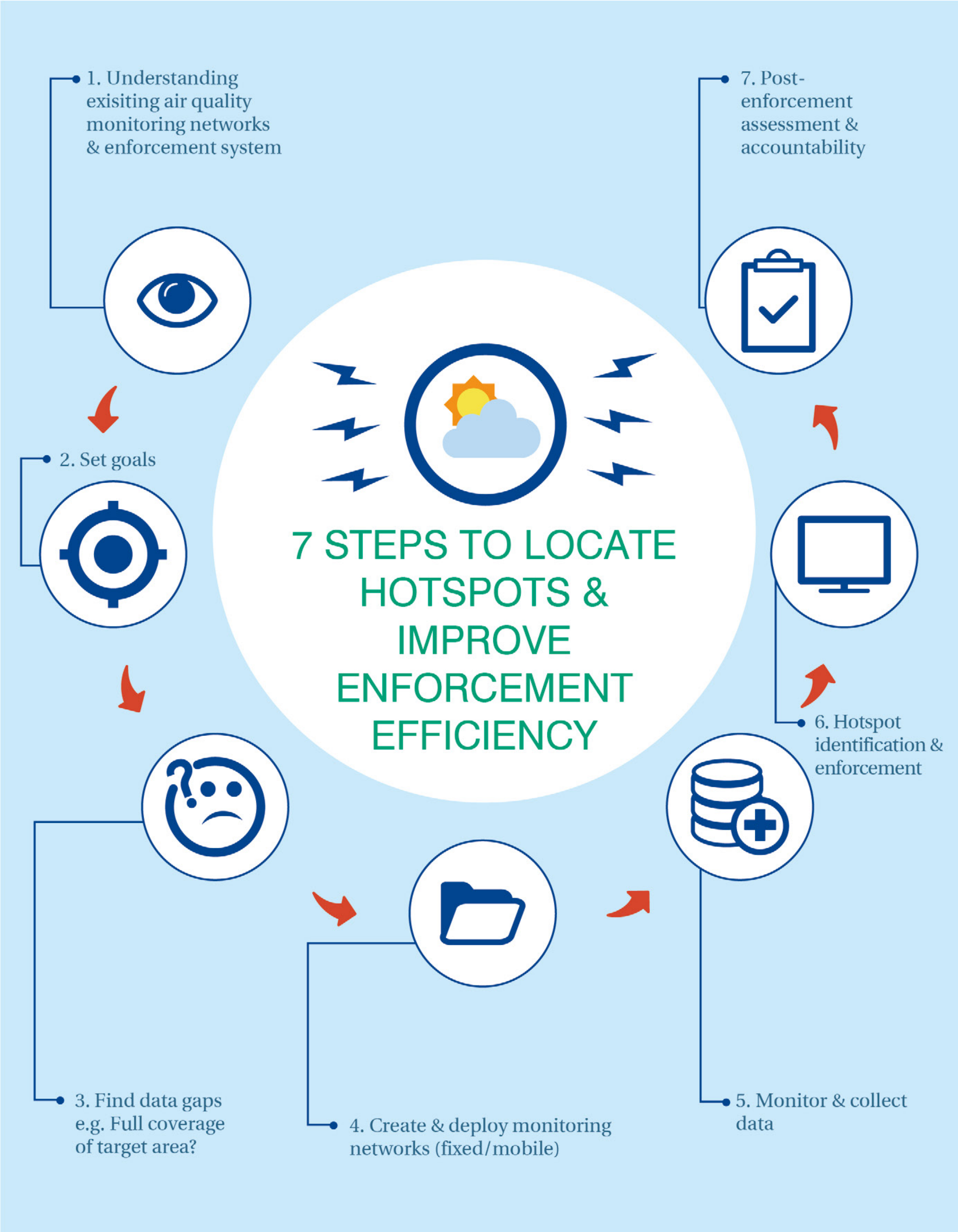
We divided the city center area of Cangzhou into 100m x 100m grids. The mobile monitoring dataset is aggregated into the 100m grids; at this stage, to ensure the mobile measurements reflect the diurnal concentration changes, we only take into account the grids with at least 8 hours measured per day to report daily hotspots. The fixed monitoring stations are also assigned to the corresponding grids. The daily mean concentration for each grid is calculated by first taking the means of stationary and mobile monitoring data in the same hour, and then calculating the mean of all hourly data in the given day. With the integrated dataset, we can identify hotspots (100m by 100m) in the next phase.

Different and complementary hotspot identification algorithms as the guidance for inspectors with different purposes

With different algorithms, we can not only find hotspots that have previously gone undetected, but also provide targeted guidance for inspectors during the inspection for a specific type of hotspot.

Evidence-based inspection process to target pollution sources

The identified hotspot grids with concentrations significantly higher than other grids. Because of the turbulent local dispersion, interactions of compounds, and restriction of sample locations, there is usually some distance between the pollution source and the identified 100-meter hotspot grid. In general, air pollution concentrations decayed with distance around a particular source, roughly 500-600m in this case. Therefore it is recommended that the inspectors conduct inspections within a 500-meter buffer around the identified hotspots and carry handheld instruments to aid their search for a pollution source if possible. Our method helps inspectors conduct an orderly investigation for sources instead of a 'Blind Search', and increases the chance of finding a potential pollution source of observed elevations. Also, the handheld instruments used by local inspectors help make the investigation for sources "evidence-based" and more accurate.


1. Understanding exisiting air quality monitoring networks & enforcement system
2. Set goals
3. Find data gaps e.g. Full coverage of target area?
4. Create & deploy monitoring networks (fixed/mobile)
5. Monitor & collect data
6. Hotspot identification & enforcement
7. Post-enforcement assessment & accountability
7 STEPS TO LOCATE HOTSPOTS & IMPROVE ENFORCEMENT EFFICIENCY

GETTING STARTED

Understanding your starting place

Cangzhou in Hebei Province has a population of around 6.9 million, distributed across 14,000 square kilometers, and is one hour away from Beijing by high-speed train. In 2020, Cangzhou's average concentration of $PM_{2.5}$ was 47 micrograms per cubic meter, which decreased by 28.8% compared with 2017. However, the average pollution level still fails to meet the national standard of 35 micrograms per cubic meter.

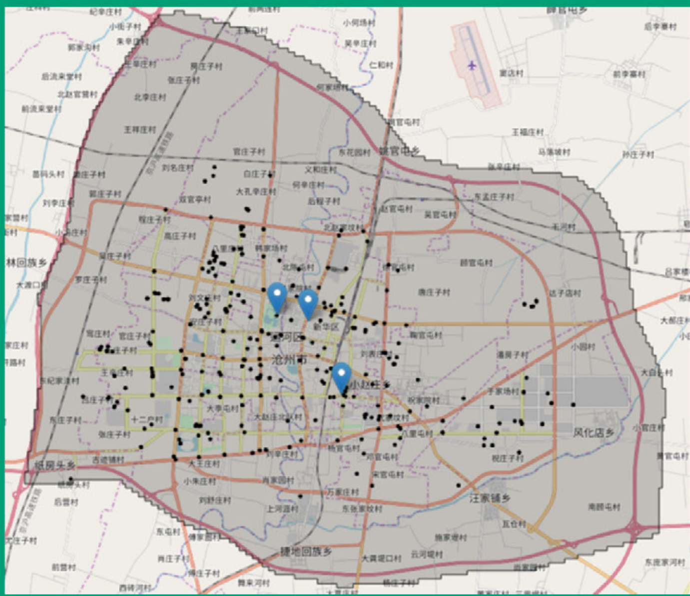


Figure 2. Spatial distribution of air quality monitoring stations in the center area of Cangzhou. The target region is shaded grey, overlaid with 3 national monitoring stations (blue markers) and 320 additional fixed monitoring stations (black markers).

The target monitoring region is in the urban center of Cangzhou city, an area of approximately 320 square kilometers that is surrounded by three major highways. The air quality in this area is often worse than in the suburbs mainly because of vehicle pollution, construction, and restaurants.

The current air quality monitoring system in Cangzhou is comprised of 3 national monitoring stations and 320 micro fixed monitoring stations within the central city area. The spatial distribution of monitoring stations is shown in the figure on the right side. (Figure 2)

One of the major environmental strategies for addressing air pollution problems at the city and local levels is inspections conducted by local environmental inspectors. An extensive system of inspection by regional and local environmental agencies has been established in Cangzhou. However, the system experienced low effectiveness in operation, which has been mainly influenced by incomplete spatiotemporal coverage of the monitoring network, and insufficient technical capacity and resources available to environmental inspectors to carry out their duties. Also, it requires all inspectors to have a full understanding of the whole city with all potential emission sources.

Set clear goals

In Cangzhou, hotspots identified by the public or existing monitoring networks which were 500m by 500m are still too general for inspection. Environmental inspectors are not able to locate sources efficiently and timely. Also, hotspot identification methods before:

- only focused on areas with elevated $PM_{2.5}$ concentrations above a certain threshold,
- failed to find locations with a high density of $PM_{2.5}$ higher than surrounding areas, and
- couldn't detect the abnormal extreme high values of the $PM_{2.5}$ concentration in long-term hotspots.

GOAL: TO LOCATE HOTSPOTS AT FINER SCALED GRIDS (100M X 100M) AND IMPROVE ENFORCEMENT EFFICIENCY.

In this guide, we use the Cangzhou Clean Air pilot project as a case study only for **one goal**: to locate hotspots accurately, and further improve the efficiency of the enforcement system to improve air quality.

Air Quality Monitoring Networks in China

The air quality monitoring networks in China expanded quickly in recent years, which is divided into four levels: national, provincial, municipal, and district (county). By the end of 2020, the number of national monitoring stations for six nationally-regulated pollutants (PM_{10}, $PM_{2.5}$, O_3, CO, SO_2, and NO_2) reached 1,436 and will further expand to 1,800 stations[3], while the total number of automatic air quality monitoring stations (deployed by local governments) is more than 5,000[4], covering all prefecture-level and above cities, and some districts and counties. (Figure 3)

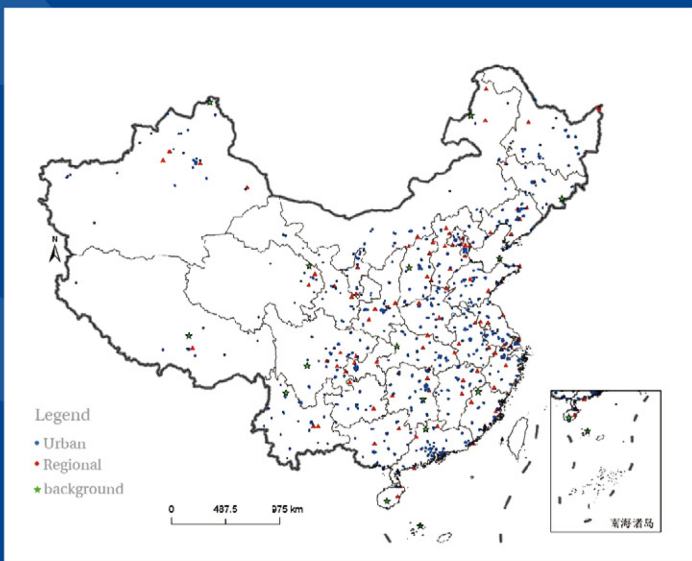


Figure 3. Air quality monitoring networks in China[5]

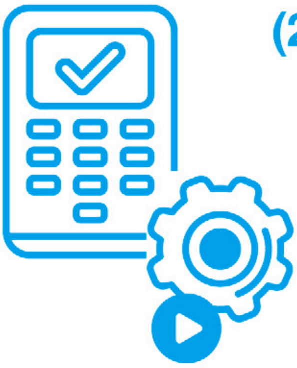
[3] http://www.gov.cn/xinwen/2020-01/10/content_5468202.htm
[4] http://www.chinanews.com/gn/2020/06-02/9201071.shtml
[5] http://www.cnemc.cn/zzjj/jcwl/dqjcwl/201711/t20171108_645109.shtml

LOCATE HOTSPOTS AT FINER SCALED GRIDS AND IMPROVE ENFORCEMENT EFFICIENCY

Cangzhou's approach

(1) Deploy monitoring networks & collect sufficient data

To increase the spatiotemporal coverage of the existing air quality monitoring network in Cangzhou, we deployed 50 taxis mounted with lower-cost sensors, which complemented and expanded the network. Then, the next step to reducing air pollution is to locate hotspots accurately at a finer scale, which is 100 meters by 100 meters with the data collected from both fixed and mobile monitoring networks, emission inventory, and traffic volume. We have collected data for two years in the Cangzhou pilot project.



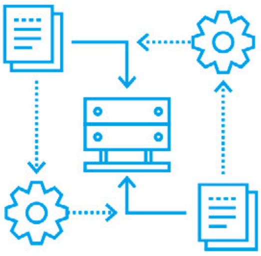
(2) Develop hotspot identification algorithms

The source apportionment of $PM_{2.5}$ in Cangzhou (2016)[6] indicates that the largest pollution in the urban area comes from coal burning and dust, which accounted for 35.6% and 20.3% respectively.

Paved and unpaved road dust, as well as construction dust, are considered to be the major $PM_{2.5}$ and PM10 emission sources. Meanwhile, vehicle emissions contributed more than 19% of $PM_{2.5}$ emissions. Environmental inspectors can't supervise these pollution sources effectively.

To help local government optimize the allocation of limited staff resources, we used the data collected from mobile monitoring, micro fixed stations, and emission inventories to develop a series of spatial and temporal analysis methodologies to statistically identify the daily pollution hotspots. Additionally, to reduce repeatedly notifying inspectors of the hotspots with known sources, we performed a time-series peak analysis algorithm to identify the anomalous activities for grids with existing sources, such as construction sites, traffic junctions, and key industrial sites.

[6] http://www.cangzhou.gov.cn/zwbz/jrcz/419135.shtml



(3) Establish enforcement procedures

The daily hotspot inspection and feedback process follows the inspection protocol shown in Figure 4, and mainly involved three steps:

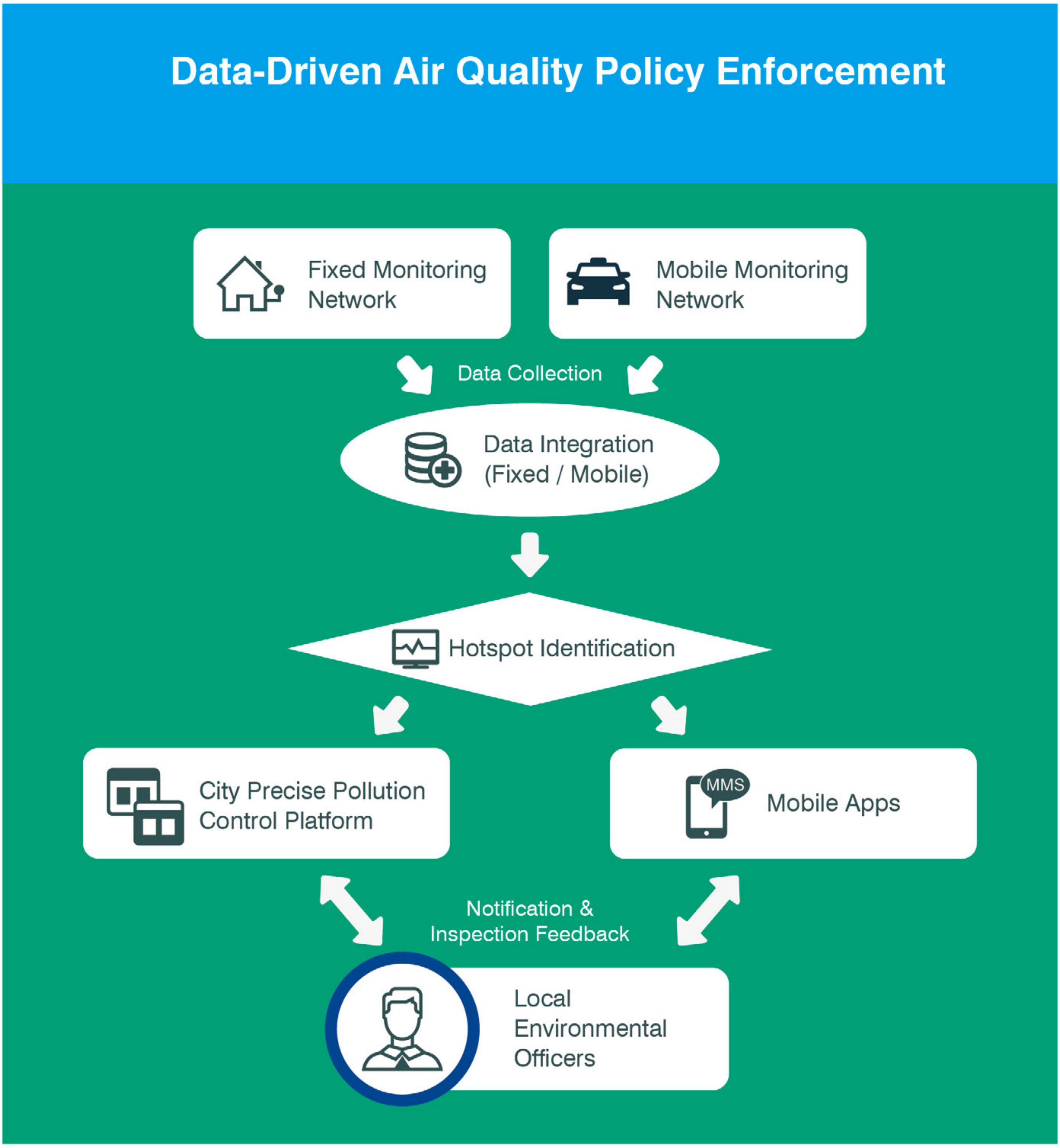


Figure 4. Flow chart of daily hotspot identification and inspection

1. Commencing field inspection:

Inspectors were required to perform on-site inspections for each hotspot on the same day the inspectors are notified (this corresponds to the day after the exceedance occurred and the same day our algorithm identified the exceedance). We provided the centroid coordinates of the hotspots to the inspectors, who were advised to patrol the area within a maximum radius of 500m, and identify potential sources that may have contributed to the observed exceedance.

2. On-site processing:

If a suspected source (e.g., dust resuspension at a construction activity) was detected, the inspectors provided suggestions and advice to the responsible parties to take actions to correct the violation.

3. Providing on-site feedback on the data platform:

Feedback was required on a hotspot-by-hotspot basis. The information recorded included hotspot ID, inspection time, district, grid ID, type of suspected source and/or violation, and detailed follow-up suggestions. (Figure 5)

Compared with the previous enforcement system, environmental inspectors can use the platform to not only feed back the results of hotspots more conveniently and quickly, but also take photos of hotspots with problems and upload them for follow-up supervision and inspection.

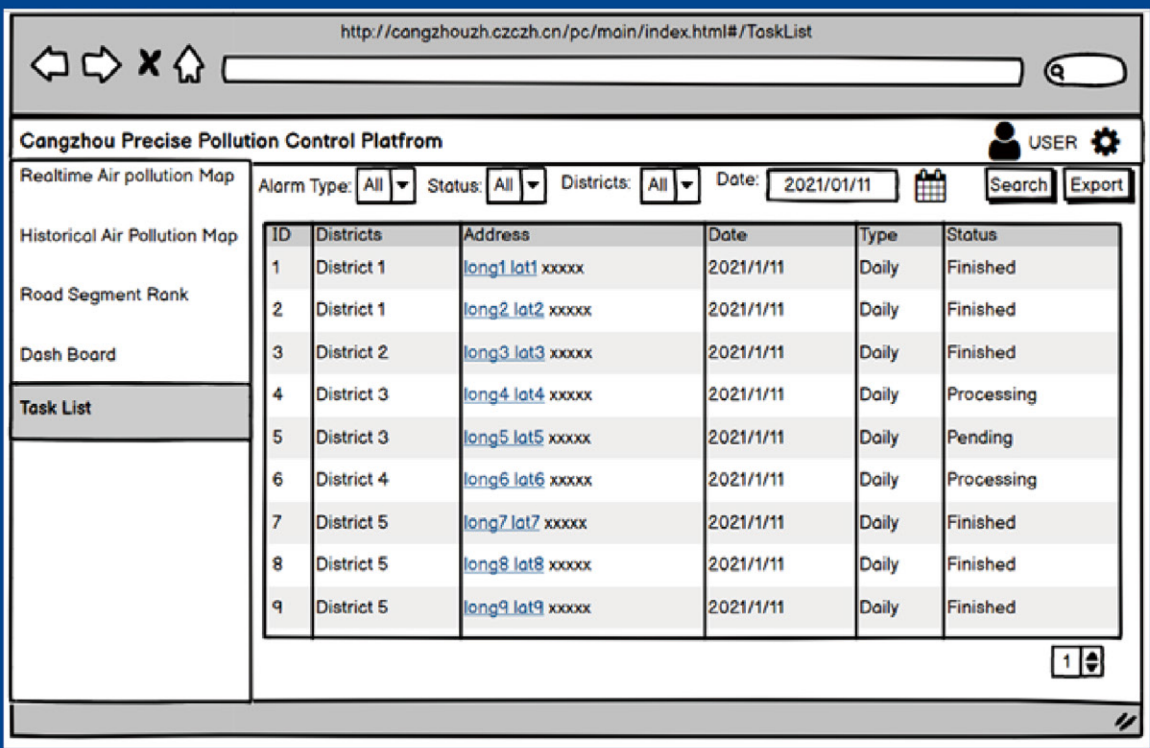


Figure 5. The interface mock up of Precise pollution control platform based on multiple sources data fusion

Additionally, during the on-site inspection, due to the different abilities of environmental inspectors on problem identification, inspectors also use advanced portable monitoring equipment – including handheld devices and drones – to assist in the inspection and determination of emission sources. (Figure 6)

Figure 6. Training on using drones to locate potential emission sources (a & b) and on-site inspection with handheld monitoring devices (c)

What did we find?

During the test period from September to November in 2020, 1336 hotspots were identified by three algorithms and 1204 of them were inspected by environmental inspectors with a feedback rate of over 90%. **Of the 1204 hotspots with feedback, suspected emission sources were reported within a 500m radius of 852 hotspots, yielding a pollution source detection rate of 71%. The majority of hotspots were caused by traffic, followed by construction, restaurants, and industry emission.** (Figure 7)

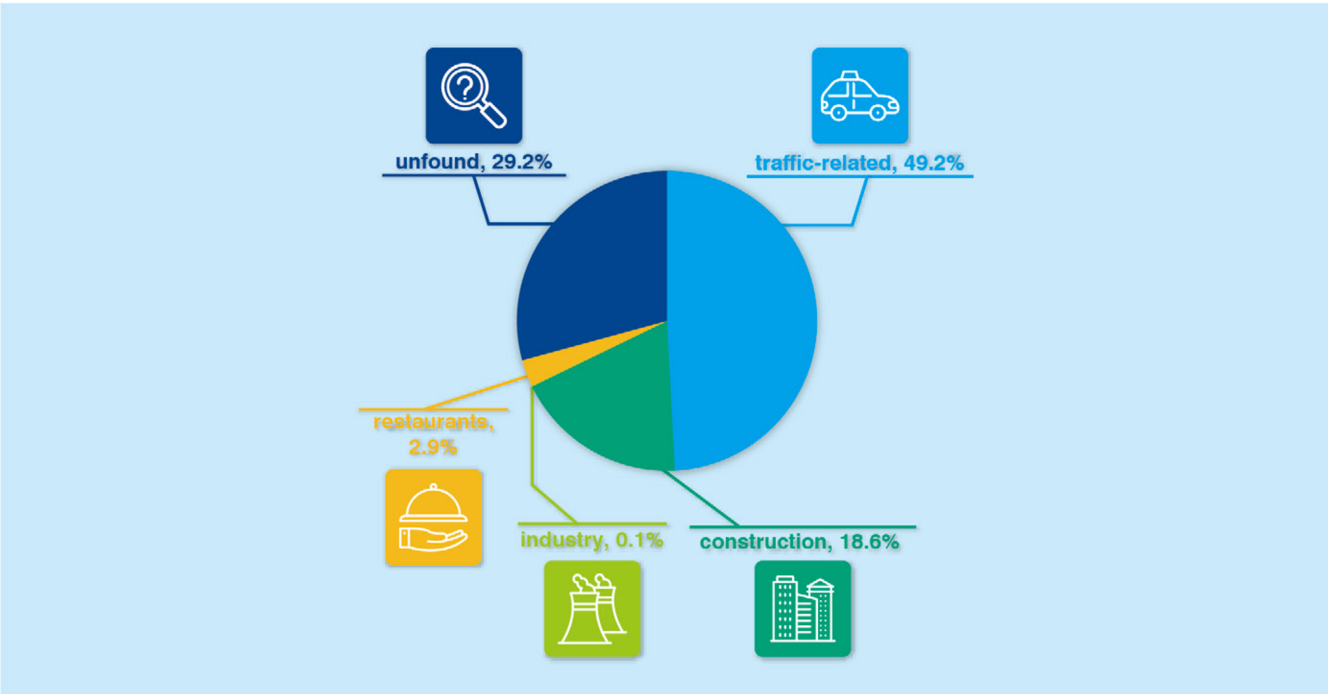


Figure 7. Emission source categories of hotspots reported by environmental inspectors

EXAMPLE – DAILY HOTSPOT RESULTED FROM CONSTRUCTION

This case study shows how interventions made after on-site inspections can improve the air quality within the grid, although it is difficult to detect due to the large variance of fractional enhancement[7] of $PM_{2.5}$ concentration in the grid.

Stage 1. Hotspot identification. Grid cell "T92223_153", located in the middle of Fengwang Road in Kaifa District, was identified as a $PM_{2.5}$ hotspot on November 13th based on the data reported by the fixed monitoring station deployed in that grid. Time of the highest $PM_{2.5}$ concentration of the grid was around 9 am on November 13th, as shown in Figure 8.

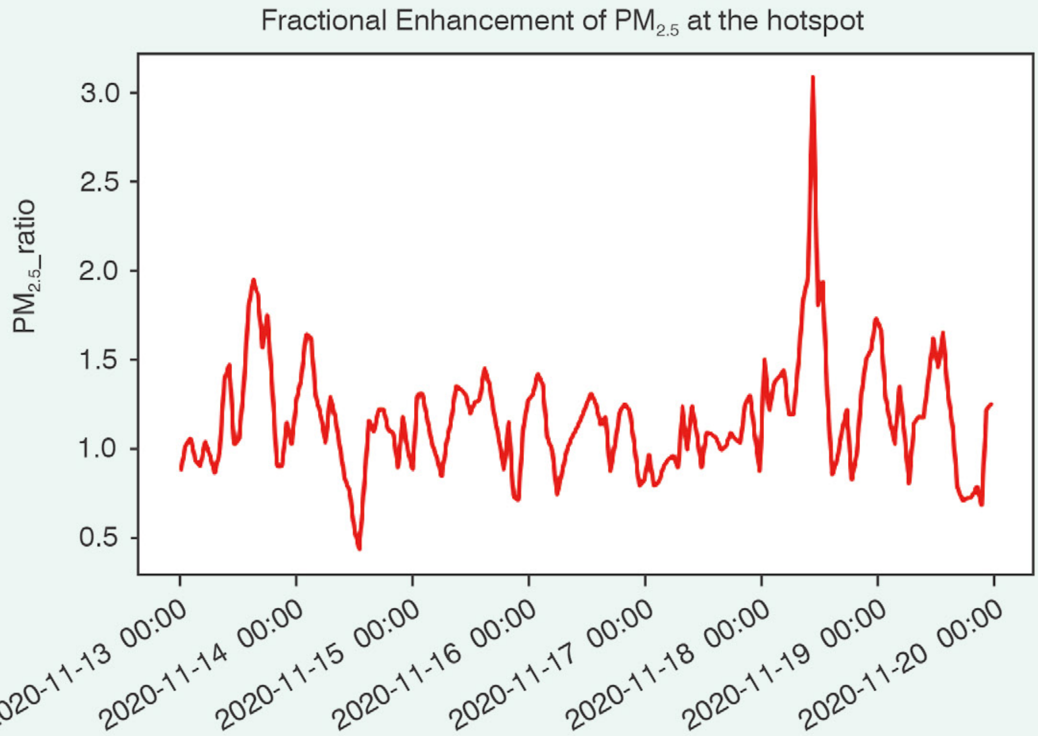


Figure 8. Fractional enhancement of $PM_{2.5}$ at a grid cell identified as a hotspot on November 13th and one week afterward, relative to the mean concentration at the 3 MEE monitors. The concentration ratios shown for the week of November 13th include measurements from two fixed micro stations located within the identified grid cell.

[7] The ratio of hotspot concentration and regulatory station concentration

Stage 2. Hotspot notification. Concentrations in this grid cell were among the top ten grids in the whole city on this day, so the grid id and supporting information were provided to the inspectors at 09:15 AM on November 14th, including daily average $PM_{2.5}$ concentration on November 13th, approximate address (from geocoding), grid centroid coordinates, and recommended inspection time based on the 3-hour-window when the observed fractional enhancement was the largest. As illustrated in Figure 9, the notification report provided to the local inspectors in the Kaifa District contained six hotspots.

Cangzhou Kaifa District Daily Hotspots (13 Nov 2020)

On November 13, there are 6 hotspots of $PM_{2.5}$ mass concentration in Cangzhou Economic Kaifa District (details below).
The investigation is recommended to be conducted within a radius of 500 meters around the given latitude and longitude coordinates.

Hotspot ID	Date	District (county)	Grid Code	Pollutant	Conc. (ug/m³)	Alarming Count	Address*	Micro Station in Grid	Daily Mean Conc. at Microsite	Recommended Investigation Time	Longitude/ Latitude on AMAP
R1	2020-11-13	Kaifa District	T92677_895	$PM_{2.5}$	64.08	3	Xiaozhaozhuang Township Xinhua District	Ecospower 437	PM_{10}: 127.04, $PM_{2.5}$: 64.08	8, 9, 10	116.898180 / 38.280874
R2	2020-11-13	Kaifa District	T92678_606	$PM_{2.5}$	68.67	1	Huanghe East Road, Kaifa District, Xinhua District	Northwest of Dongfang shiji Home 343	PM_{10}: 123.33, $PM_{2.5}$: 68.67	9, 10, 21	116.908257 / 38.288931
R3	2020-11-13	Kaifa District	T92223_153	$PM_{2.5}$	58.75	6	Haihe East Road, Kaifa District, Xinhua District	Northwest of Huayuxin Yuan Community 741	PM_{10}: 126.46, $PM_{2.5}$: 58.75	9, 10, 18	116.932993 / 38.275503
R4	2020-11-13	Kaifa District	T92679_840	$PM_{2.5}$	71.12	1	No.46 Jiuhe East Road, Cang County	Yameijia 10740 Yameijia 392	PM_{10}: 137.18, $PM_{2.5}$: 71.12	2, 8, 9	116.957729 / 38.282665
R5	2020-11-13	Kaifa District	T92680_69	$PM_{2.5}$	56.20	1	Cang County			3, 0, 1	116.965975 / 38.305046
R6	2020-11-13	Kaifa District	T93136_647	$PM_{2.5}$	81.73	6	Yongji East Road, Cang County	Southwest of Zhongnan Hitech	$PM_{2.5}$: 98.71	9, 19, 21	116.973304 / 38.314894

* Addresses for reference only. The longitude and latitude coordinates shall prevail.

Figure 9. Report of hotspots provided to the inspectors in Kaifa District on November 14th.

Stage 3. Field Inspection. The list included the target grid "T92223_153"(Figure 10). After the information of the grid was reported to the local inspectors, an on-site investigation was recommended to be performed on the grid and its surrounding areas at 9am, 10am, and 6pm on November 14th (Figure 9). Inspectors arrived at the hotspot around 9:30am on November 14th.

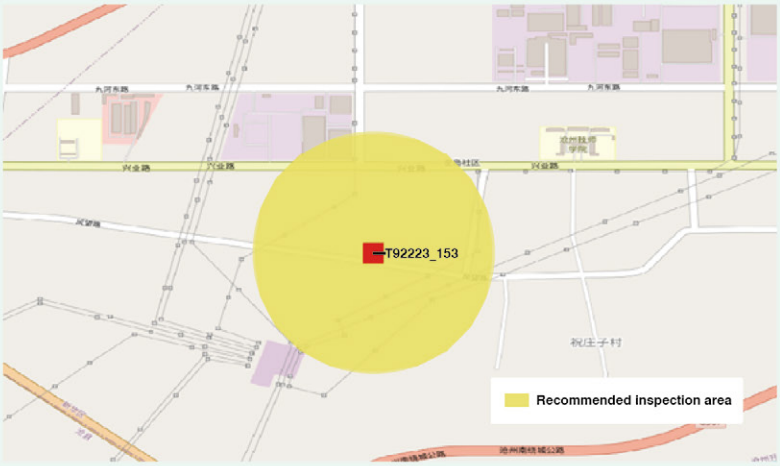


Figure 10. Location of the hotspot "T92223_153" and the recommended inspection area.

Stage 4. Emission Source Identification. Inspectors provided feedback that they found a construction site was not applying mulch to protect exposed soil from both wind and water erosion, (Figure 12), which is one of the required measures to control construction dust. This activity was occurring roughly 60 m away from the grid cell centroid.

Figure 12. Photos of on-site inspection of "T92223_153" on November 14th.

Stage 5. Enforcement. Inspectors ordered the construction site manager to take dust control measures on site, which included spraying water during field operation and covering exposed soil with mulch.

Stage 6. Feedback. Inspectors provided written feedback on the hotspot by 9:42am on November 14th, within the same hour the hotspot report was issued.

After the inspection was carried out, the fractional enhancement dropped to 1.1 on average over the week within this grid cell (Figure 11). And there was about a 7% reduction of fractional enhancement before and after inspection. However, it is important to note that fractional enhancement at this location is highly variable during the week of November 14-20th and particularly high on November 18th. The notable peak on the 18th was detected but not reported because it did not meet the criteria we set in the peak detection method. The small improvement in fractional enhancement before and after inspection may not exceed the natural variability of air pollution at this site, and thus we could not clearly attribute it to inspection.

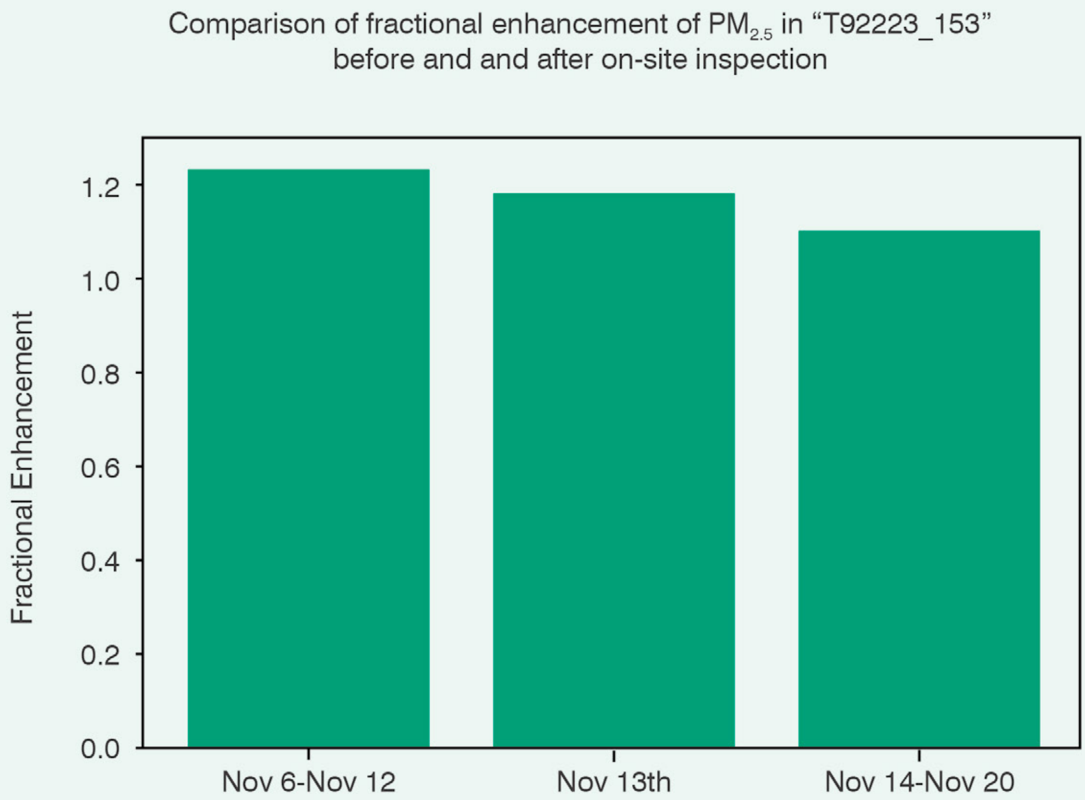


Figure 11. Comparison of fractional enhancement of $PM_{2.5}$ in “T92223_153” before and after on-site inspection.

What next?

During the test period, we've noted that the location where most of the 320 fixed stations are deployed is visited by a large number of taxis (Figure 13). Are there any fixed stations that could be substituted by mobile monitoring data?

We can tell some fixed stations are close to each other, and the average distance between each fixed station and its nearest fixed site is 222 meters. Is it possible to remove or relocate certain fixed stations?

Since the routes visited by taxis are largely influenced by human activities, and we find that the coverage tends to be stable when the number of taxis reaches a certain level. Is it possible to reduce the current number of taxis deployed in Cangzhou while maintaining monitoring efficiency?

The mobile monitoring data collected by taxis can provide insights on the air quality trends. Is it possible to evaluate an intervention primarily relying on both fixed and mobile monitoring data?

The hyperlocal dataset can describe urban pollution characteristics at a finer scale. Can we use it to help the city develop more targeted air pollution control programs or support urban planning, land use zones, and other decision-making processes?

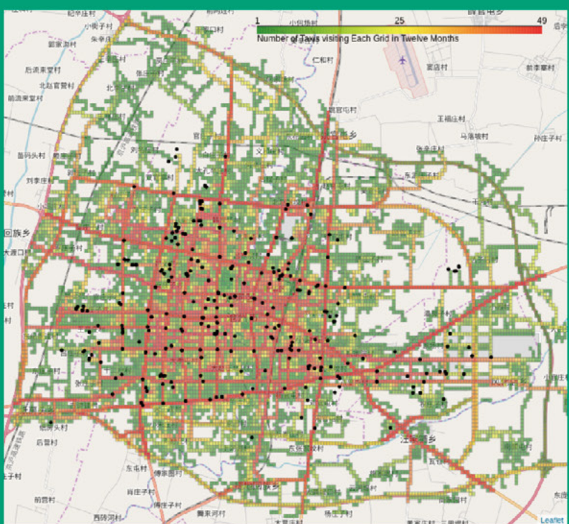


Figure 13. The number of taxis visiting each 100-meter grid in 2019. The locations of 320 fixed monitoring stations are shown in black markers.

CONCLUSION

Cangzhou's hyperlocal monitoring can characterize the air pollution at the street level, allow environmental inspectors to identify hotspots at a finer scale, and improve their enforcement efficiency. The project gained scientific and technical insights into how to ensure the reliability of mobile data collected and how to reduce the uncertainty of the hotspot identification, which can serve as a starting point for any city embarking on a mobile monitoring effort. Also, we gained other valuable insights regarding the optimization of existing monitoring networks and the evaluation of interventions to improve air quality.

ACKNOWLEDGEMENTS

The Cangzhou pilot project was delivered by a consortium led by Environmental Defense Fund China (EDF China), Beijing Huanding Environmental Big Data Institute (HD Environmental Consortium), and Southern University of Science and Technology Environmental Innovation Center (SUSTech EIC), and convened by the Government of Cangzhou City. This project was jointly funded by the Clean Air Fund, the Children's Investment Fund Foundation (CIFF) and other Environmental Defense Fund donors. EDF China and the project consortium would like to thank the scientific and project advisors, technology partners for their contributions and support through different phases of the project. The lessons and insights gained from the Cangzhou pilot project draw from these collective efforts.

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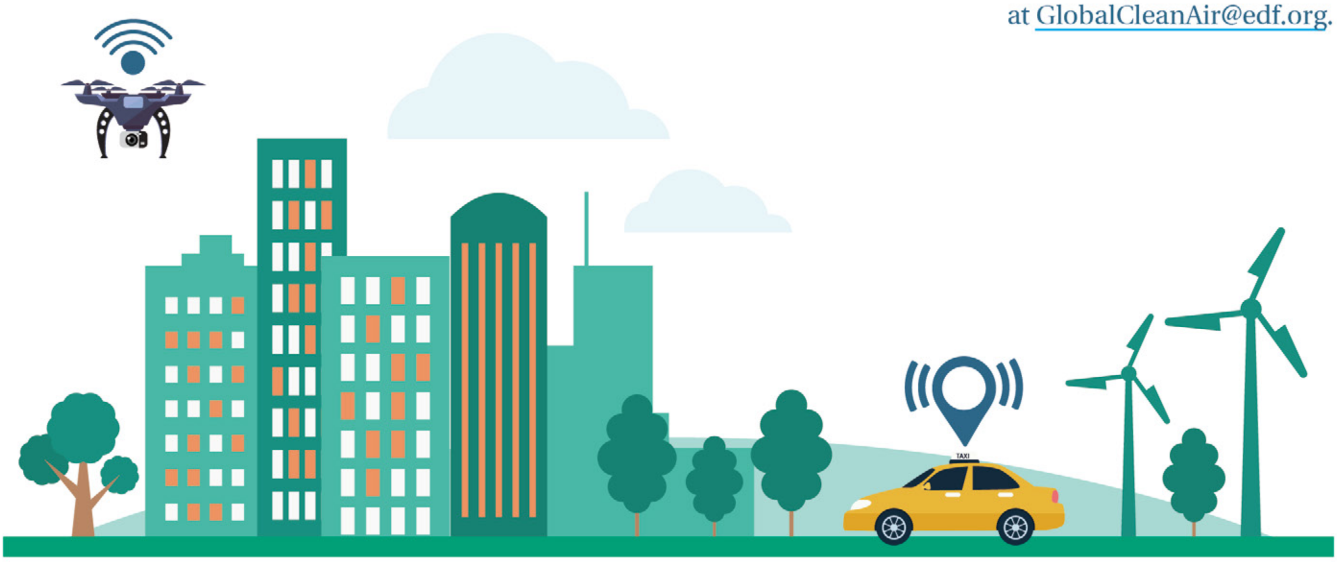

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